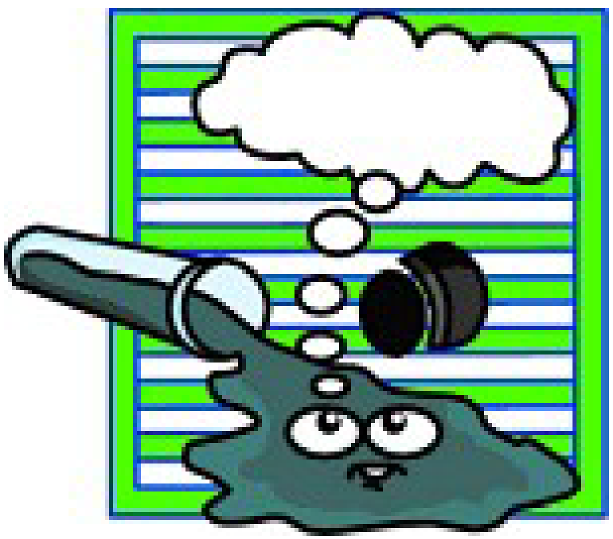
Chemistry I
Solutions



Here's why

- A lot of chemical processes take place while the reactants are in solution, usually a water solution.

Mixtures

- **Mixtures** are the physical combination of two or more substances that retain their identities.

- mixtures can be separated into their components by physical (mechanical or thermal) means.

Specific types of mixtures

- Mixtures come in one of three forms:
    1. solutions
    2. suspensions
    3. colloids.

suspensions

- A suspensions are *heterogeneous* mixtures where the particles will settle out.
- Example: muddy water

colloids

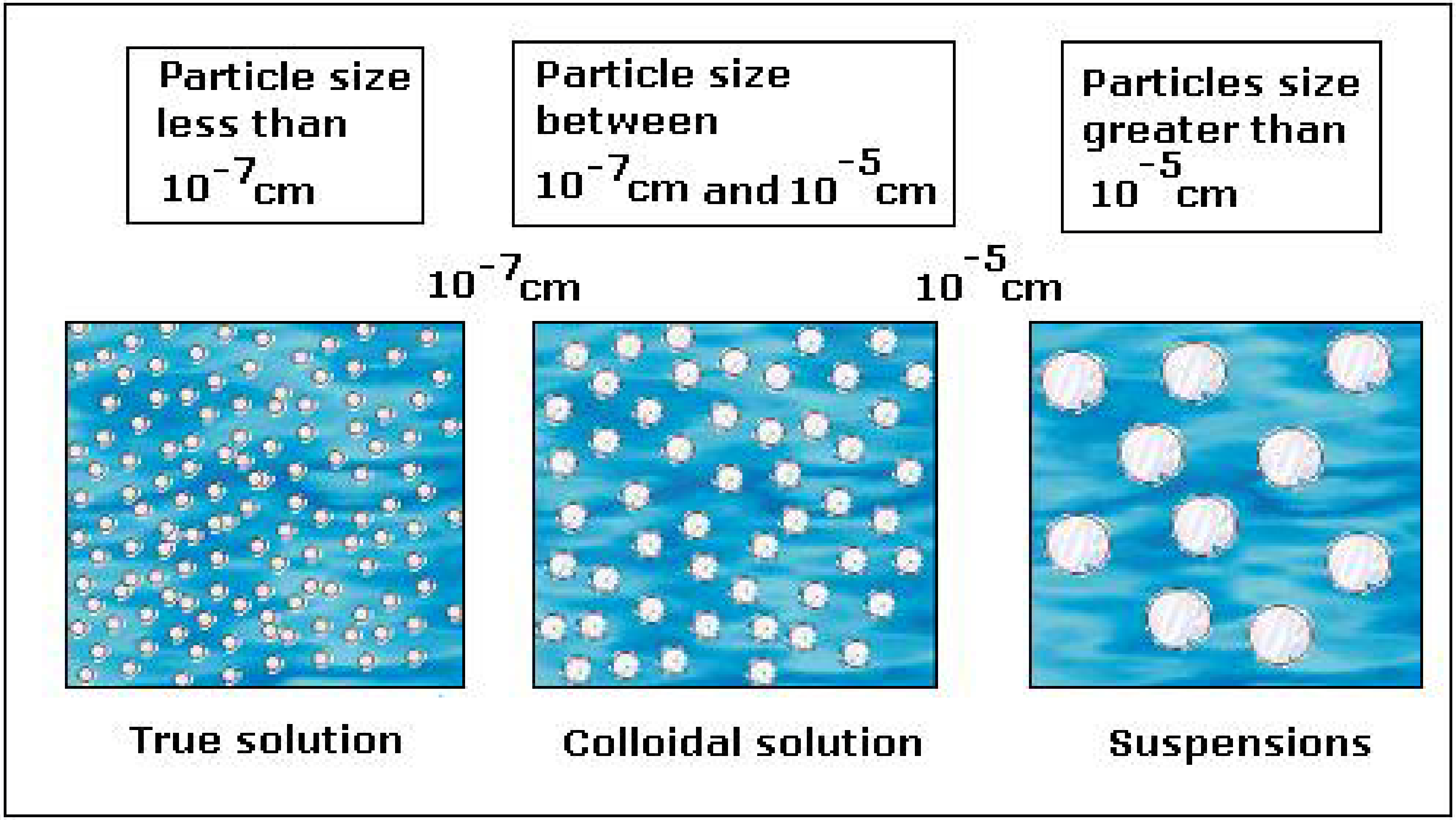
- Colloids are substances where the particles are dispersed throughout the “solvent” and are too small to see with the eye.

- Example: milk

Solutions

- Solutions are defined as homogenous mixtures of two or more components.
- Example: ice tea, lemonade

solutions, suspensions, & colloids



Other mixtures

- An **aerosol** is a colloid of fine solid particles or liquid droplets in a gas.
  - Examples are clouds, and air pollution such as smog and smoke.

Other mixtures

- An **emulsion** is a mixture of two or more liquids that are normally immiscible (not mixable).
- Emulsions are colloids.. Although the terms *colloid* and *emulsion* are sometimes used interchangeably.

Examples of emulsions

- Include vinaigrettes and milk.
- The photo-sensitive side of photographic film is an example of an emulsion.

Other mixtures

- A **foam** is a substance that is formed by trapping pockets of gas in a liquid or solid.
- Examples: bath sponge and firefighting foams
- In most foams, the volume of gas is large, with thin films of liquid or solid separating the regions of gas.

Testing for true solutions

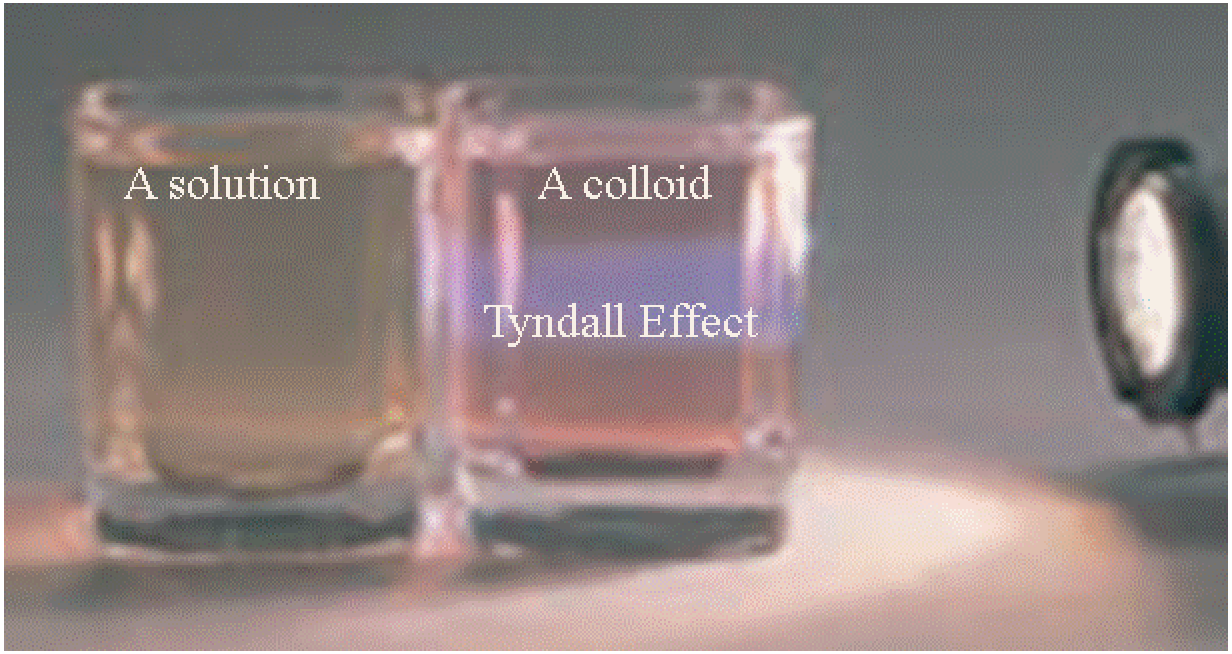
- colloidal suspensions exhibit light scattering.
- A beam of light or laser will trace a visible path through a genuine colloidal suspension.
- e.g. a headlight on a car shining through fog.

- a beam of light or laser light will not trace a visible path through a true solution

Tyndall Effect (If you really want to know)

- Tyndall scattering occurs when the dimensions of the particles that are causing the scattering are larger than the wavelength of the light that is scattered.
- It is caused by reflection of the incident light from the surfaces of the particles.

Tyndall Effect



True Solutions

- In true solutions, the solute will not come out of solution with out a change in temperature and/or pressure.

the parts of a solution

- all solutions have two basic parts.
- They are:
  - 1. Solute which is the substance being "dissolved"
  - 2. Solvent which is the substance doing the dissolving.
  - 3. The substance in greatest percentage is usually considered to be the solvent.

Nine combinations of solvents &solutes

Solvent	Solute	Example
Gas	Gas	Air
Liquid	Gas	Soda
Solid	Gas	Hydrogen on Pt
Gas	Liquid	Water vapor in air
Liquid	Liquid	antifreeze in water
Solid	Liquid	Cu in Hg
Gas	Solid	C in air (soot)
Liquid	Solid	Sugar in water
Solid	Solid	pewter

Solvents & Solutes

- . The ability of a solute to mix with a solvent is called solubility.
- Some solutes are only slightly soluble in a given solvent
- Some solutes are very soluble in a given solvent.
- This appears to be temperature dependent.

“ Like dissolves like”

- A General rule applied to solute-solvent relationships goes like this: “ Like dissolves like”
- There are two types of solutes and solvents.
  - They are polar and nonpolar.
- SO polar solutes will dissolve in polar solvents
- nonpolar solute will dissolve in nonpolar solvents.
- And there are some substances that can be both polar and nonpolar because of molecular structure.

“ Like dissolves like”

- Solvents can be selective about what solutes they will dissolve due to electronic structure.

solvents & molecular structure

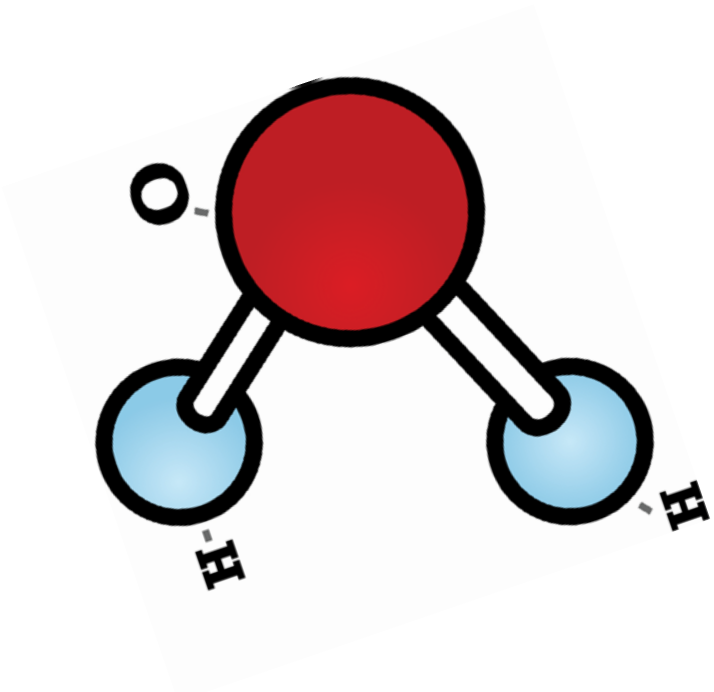
- Water is the universal solvent
- it is a polar solvent.
- Water is polar because of the dipole that develops on the molecule.
- This occurs because oxygen does not share the electrons equally.

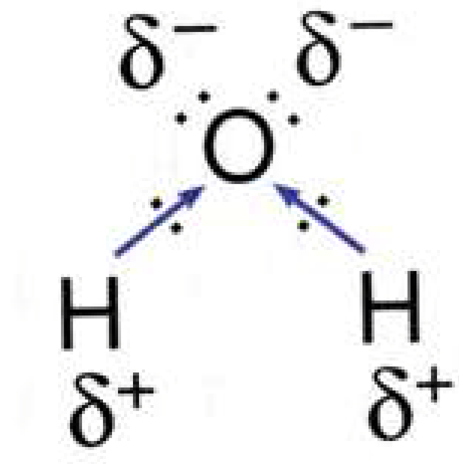
Water

- The electrons from the hydrogen atoms spend most of the time close to the oxygen atom.

- This creates a negative charge (pole) on the oxygen atom and a positive charge (pole) on each of the hydrogen atoms

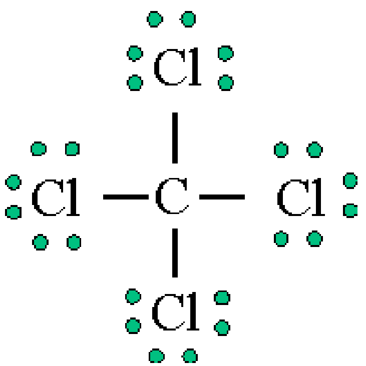
Water molecule



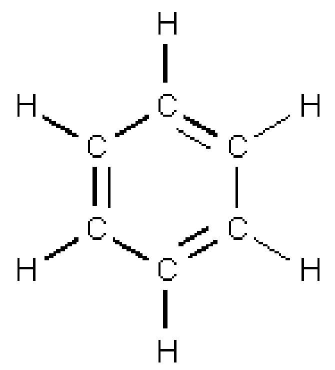


Nonpolar solvents

- Some organic substances such as carbon tetrachloride and benzene are nonpolar solvents.



carbon tetrachloride



benzene

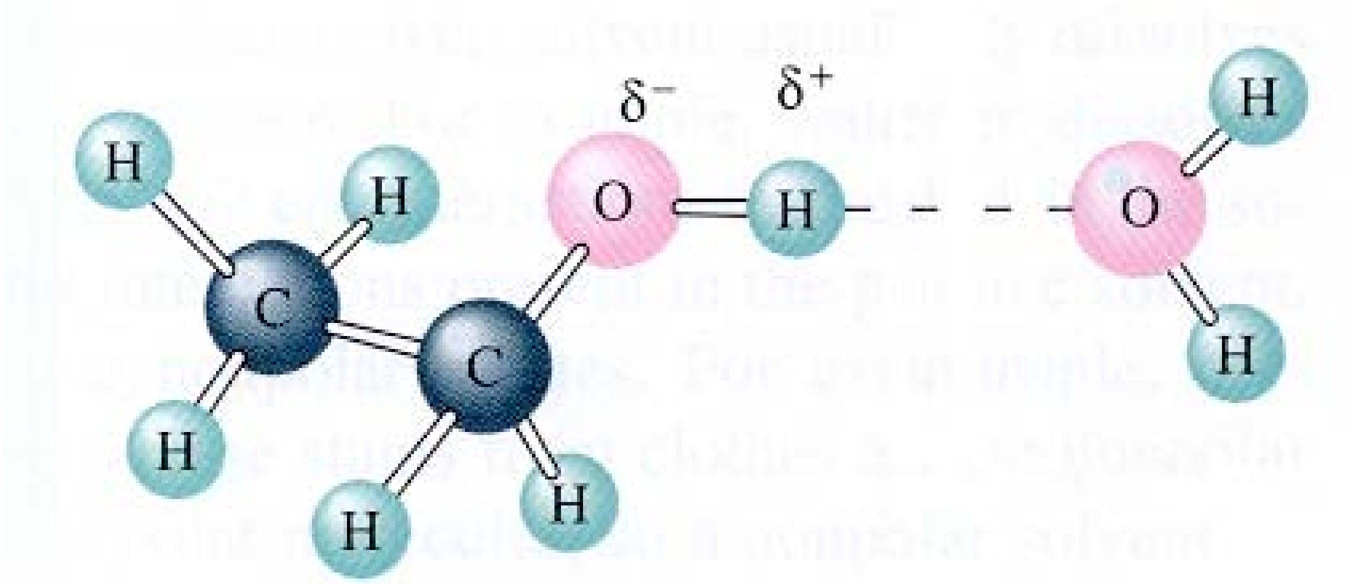
Nonpolar solvents

- This is due to an even electronic distribution.
- Therefore they will dissolve nonpolar solutes and will not dissolve ionic compounds.

Solvents that are both polar & nonpolar

- Alcohols such as methanol, ethanol, and glycols (antifreeze) are both polar and nonpolar.
- The functional group of the alcohols is the hydroxyl group, **-OH**.
- The electronegativity of oxygen is substantially greater than that of carbon and hydrogen.
- the covalent bonds of this functional group are polarized so that oxygen is electron rich.

Alcohol molecule showing polarity



Solutes & Solvents Summary

- Generally **polar solute** molecules will **dissolve** in **polar solvents**
- **non-polar solute** molecules will **dissolve** in **non-polar solvents**.

Solutes & Solvents

- The polar solute molecules have a positive and a negative end to the molecule.
- If the solvent molecule is also polar, it will have a positive and negative end.
- The opposite ends of the 2 types of molecules will attract. (plus to minus and minus to plus)
- This is a type of intermolecular force known as dipole-dipole interaction.

Solutes & Solvents

- All molecules have a type of intermolecular force much weaker than the other forces called London Dispersion forces.

- This gives the non-polar solvent a chance to solvate the solute molecules.

Le Chateliers Principle applied to solutions

- Most solutions will achieve an equilibrium where the amount of solute in a specific amount of solvent is stable at given conditions.
- However, when a stress occurs the equilibrium will find a new set of conditions.

Le Chateliers Principle applied to solutions

- Stresses that can be applied to a solution:
  - agitation (shaken),
  - addition of heat;
  - lose of heat,
  - the addition of pressure.
- The solution will make adjustments to the change in conditions.

Equilibrium & saturation

- Saturation is the maximum amount of solute dissolved in the solvent.
- If The conditions are stable(not changing) then the amount of solute going into solution is the same as the amount of solute coming out.
- The conditions are said to be at equilibrium.

Equilibrium & saturation

- saturation at equilibrium is dynamic meaning that the saturation point will change if the conditions change.
- It means that some amounts of solute will move in and out of solution.
- If the system is at equilibrium then equal amounts of solute will dissolve and recrystalize at the same time.

Equilibrium & Saturation & Change

- Depending on the direction of the change in the equilibrium two things can happen.
  - First some of the solute may come out of solution
    - in liquid/solid systems where some of the solid precipitates out
    - in liquid/ gas systems when the solution seems to "foam" up.

when conditions change

– Second the equilibrium may move in a direction to allow the solvent to dissolve more solute such as most of the compounds shown on the solubility curve.

Solubility redefined

- Therefore we must adjust the definition of solubility to include conditions.
- solubility is **the maximum amount of solute that can dissolve in a given amount of solvent under certain conditions.**

saturated and unsaturated defined

- At a given set of conditions:
  - a solution that can hold the maximum amount of solute is said to be *saturated*.
  - a solution that does not have the maximum amount of solute is said to be *unsaturated*.

concentration

- Concentration is the amount of solute in a given amount of solvent.

Concentration

- These are qualitative terms and are relative (subject to personal interpretation).
  - Concentrated means a large amount of solute in the solution
  - dilute means there is a small amount of solute in the solution.

Concentration

- Quantitative concentration uses numbers to express the amount of solute in a given amount of solution or solvent.

three main quantitative terms for concentration

– three main terms used are
  - percent by weight,
  - moles per liter of solution (molarity)
  - moles per kilogram of solvent (molality).

Pressure & Solutions

1. Pressure has very little effect on liquid/liquid solutions.
2. Pressure has very little effect on solid/liquid solutions.
3. Pressure has huge effect on gas/liquid solutions.

Gases in Solution

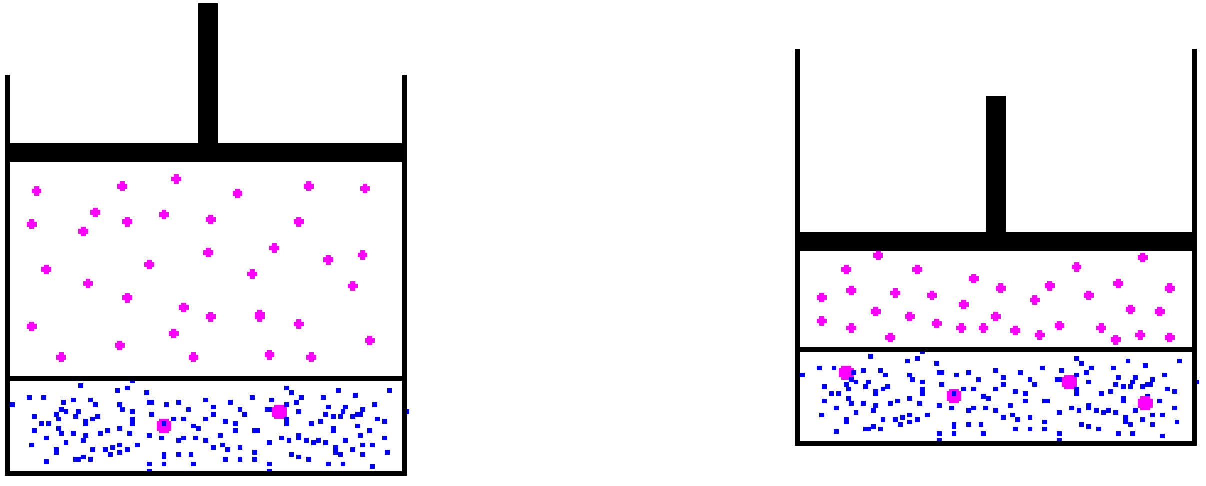
- As the pressure on the gas over the solution increases; the concentration of the gas in the solution increases.
- This system follows two laws.
  - Le Chateliers Principle
  - Henry's Law both apply to liquid/gas systems

Henry’s Law

- Henry's Law states that the solubility of a gas in a liquid is directly proportional to the pressure of the gas above the liquid.

$$\frac{C_1}{P_1} = \frac{C_2}{P_2}$$

Henry's Law



Henry’s Law

- Carbonated beverages are an example of Henry's law in everyday life.

- The dissolved carbon dioxide stays in solution in a closed bottle or can where the partial pressure of carbon dioxide was set at a high value during bottling.

Henry’s Law

- When the can or bottle is opened the partial pressure of CO_2 is much lower and the dissolved carbon dioxide will gradually escape from the soda.
- When the new low partial pressure equilibrium is established the soda will be "flat" .

Gases in Solution

- This loss of dissolved carbon dioxide will happen faster for warm soda than for cold

Why did my soda explode?

- if the pressure is quickly released; the gas will rapidly come of solution.
- The rapid release of a gas from a gas/liquid solution is called *effervescence*.
- Best example a shaken soda.

gas/gas solutions & Dalton's Law of Partial Pressure

- If you have a mixture of gases as the solute in a gas/ liquid solution, the solubility of each gas solute is proportional to its partial pressure.
- Or each gas dissolves to the same extent that it would if the other gases were not there.

Temperature & Solutions:

- Some general things about solubility and temperature.
  - The solubility of a gas decreases as the temperature of the solvent increases.
  - Temperature has little is any affect on liquid/liquid solutions.

Temperature & Solutions:

- Generally, increasing the temperature increases the solubility of solids in liquids.
- Another way to say this is increasing temperature increases concentration

What three conditions affect the solubility of a solid in a liquid?

- They are:
  - nature of the liquid solvent
  - the nature of the solid solute
  - the temperature.

Temperature & Solutions:

- Temperature has the most effect on solid in liquid systems.
  - When temperature is increased the dissolving process increases.
  - This happens because there is more kinetic energy in all if the particles involved and attractive forces are more easily overcome.

Supersaturation defined

- Supersaturation is defined as a condition where an excess amount of solute remains in solution at a lower temperature.
  - this condition is unstable.
  - It is so unstable that even a slight tap on the container or addition of a small crystal will cause the excess solute to precipitate out of solution.

3 ways help to increase the rate at which a solid will dissolve in a liquid

- 1. By stirring the solution (increase dispersion of solute)
- 2. By powdering the solid (increases surface area)
- 3. By heating the solvent (increases particle activity)

Why do these three methods work?

- 1. stirring the solution increases dispersion of the solute
- 2. By powdering the solid increases surface area for the solvent to work
- 3. heating the solvent increases particle movement

the mechanism of dissolving

- Three actions occur:
- 1. Solute particles are separated (endothermic process)
- 2. Solvent particles are moved apart to make room for the solute particles
- (endothermic process)
- 3. Solute particles are attracted to the solvent particles (exothermic process)

energy &the dissolving process

- 1. separating solute particles requires energy (endothermic process)
- 2. moving solvent particles apart to make room for the solute particles requires energy

  (endothermic process)
- 3. Solute particles attracted to the solvent particles releases energy

  (exothermic process)

What happens doing energy changes in the dissolving process?

- net change is endothermic, temperature decreases as solid dissolves and solubility increases as temperature increases.

- If net change is exothermic, temperature increases as solid dissolves and solubility decreases with increasing temperature

entropy and dissolving related

- back to the entropy and lower energy state thing.
- Natural processes tend to go toward a lower energy state.
- If a dissolving process is endothermic; it is because the entropy of the system increases.
- Dissolving a gas into a liquid produces a decrease in entropy and is also exothermic.
- So, solubility should decrease with increasing temperature and does.

heat of solution

- The heat of solution is the change in energy that occurs when a substance dissolves in a solvent.
- is measured in kilojoules per mole of solute dissolved in a specific number of moles of solvent,
- If dissolving is endothermic, the heat of solution is positive
- If dissolving is exothermic, the heat of solution is negative

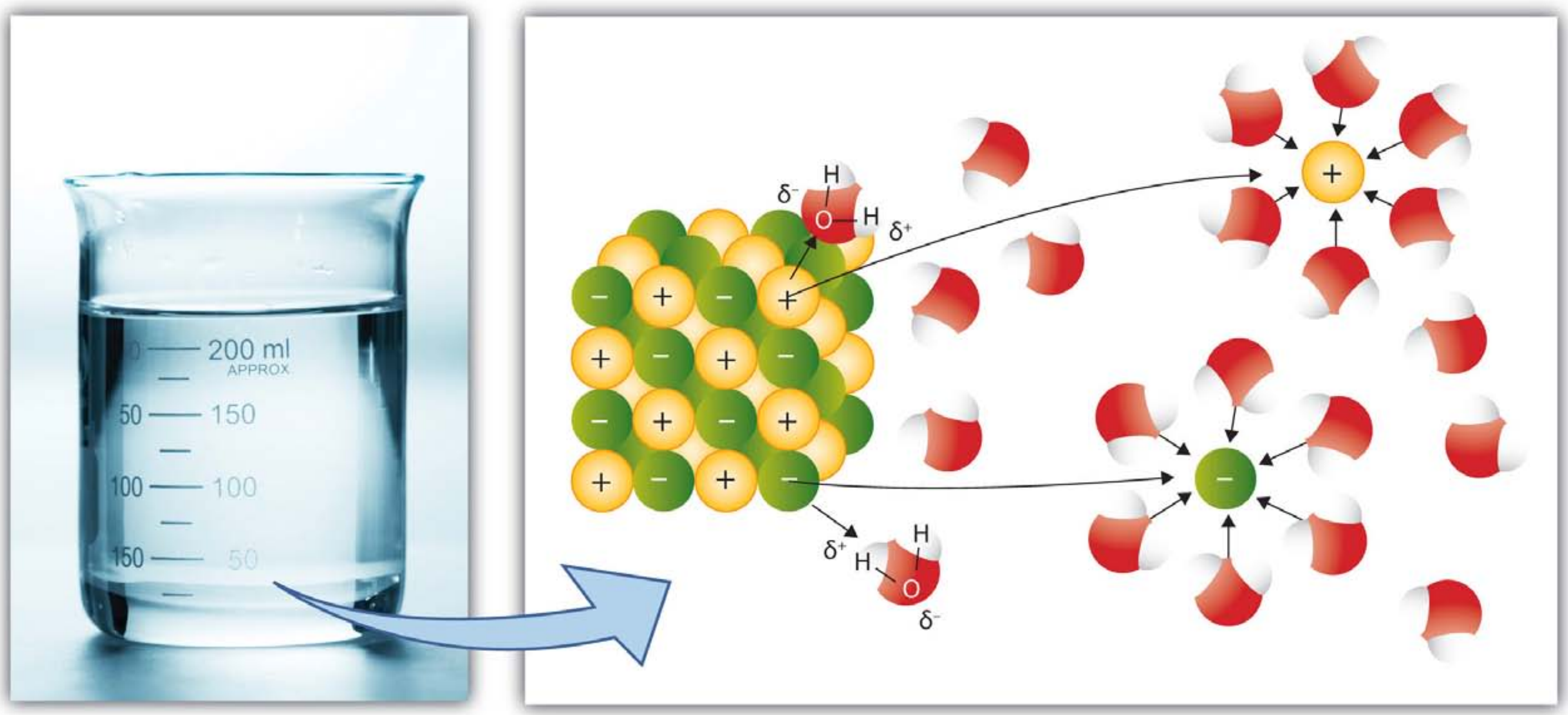
some other things going on in solutions

- Solvation is the process by which particles of the solvent pull particles of solute away from the solute crystal.
- Hydration occurs when molecules of water surround particles of solute in solution.

the terms miscible & immiscible

- They apply to liquid/liquid solutions
  - Miscible means the two liquids will mix
    - example: antifreeze and water
  - Immiscible means the two liquids will not mix
    - example: oil and water

In the solution.



Colligative properties

- Colligative properties depend only on the number of dissolved particles in solution and not on their identity.
- Non-colligative properties depend on the identity of the dissolved species and the solvent.

four colligative properties

- There are four:
  - Vapor pressure changes
  - Freezing point depression of the solvent
  - Boiling point elevation of the solvent
  - Osmotic pressure

Why do these properties change?

- The reason for the change is because the particles of solute interfere with the particles of solvent.
  - Example: freezing particles of solvent can’t get close to each other to allow attractive forces to take over.

vapor pressure change

- As solute is added to a solvent, the vapor pressure over the liquid will increase which will this increase the boiling point.
- The math relation looks like this:

  $\Delta P_{vapor} \propto m$ where ΔP_{vapor} is the vapor pressure and m is molal concentration.

freezing point depression

- As solute is dissolved into a solvent, the freezing point of the solvent is lowered.
- Mathematically the amount the fp is lowered is directly proportional to the molal concentration.

Freezing point depression math

- There are 3 variables needed to calculate fp depression. They are :
  - ΔT_f m where ΔT is change in temperature and m is molal concentration.
  - K_f is called the freezing point constant: it is the amt of change the fp will undergo for a 1 molal solution. Fp will go down.

math formula needed to calculate fp change

$$\Delta T_f = (m)(K_f)(\#\text{particles})$$

boiling point elevation

- When a solute is dissolved into a solvent, the boiling point of the solvent is raised.
- This depends on the amount of solute dissolved into the solvent.
- the amount the bp increases is directly proportional to the molal concentration.

Boiling Point Elevation

- The math looks like this:
  - $\Delta T \alpha m$ where ΔT is change in temperature and m is molal concentration.
  - K_b is called the boiling point constant: it is the amt of change(raising) the bp will undergo for a 1 molal solution.

What is the math formula needed to calculate bp change?

$$\Delta T_{bp} = (m)(K_b)(\#\,\text{particles})$$

Classifying Solutions

- If the solution:
  - can conduct electricity.
  - cannot conduct electricity.
- If the solute will:
  - produce ions in water solution.
  - Break into molecules in water solution.

Electrolytes & nonelectrolytes

- Substances that can dissolve in water and the solution can conduct electricity are called *electrolytes*.
- Substances that can dissolve in water and the solution cannot conduct electricity are called *nonelectrolytes.*
- *We will now focus on electrolytes*

electrolytes in water solutions

- These compounds will produce ions in water solutions.

- These solutions are called aqueous solutions

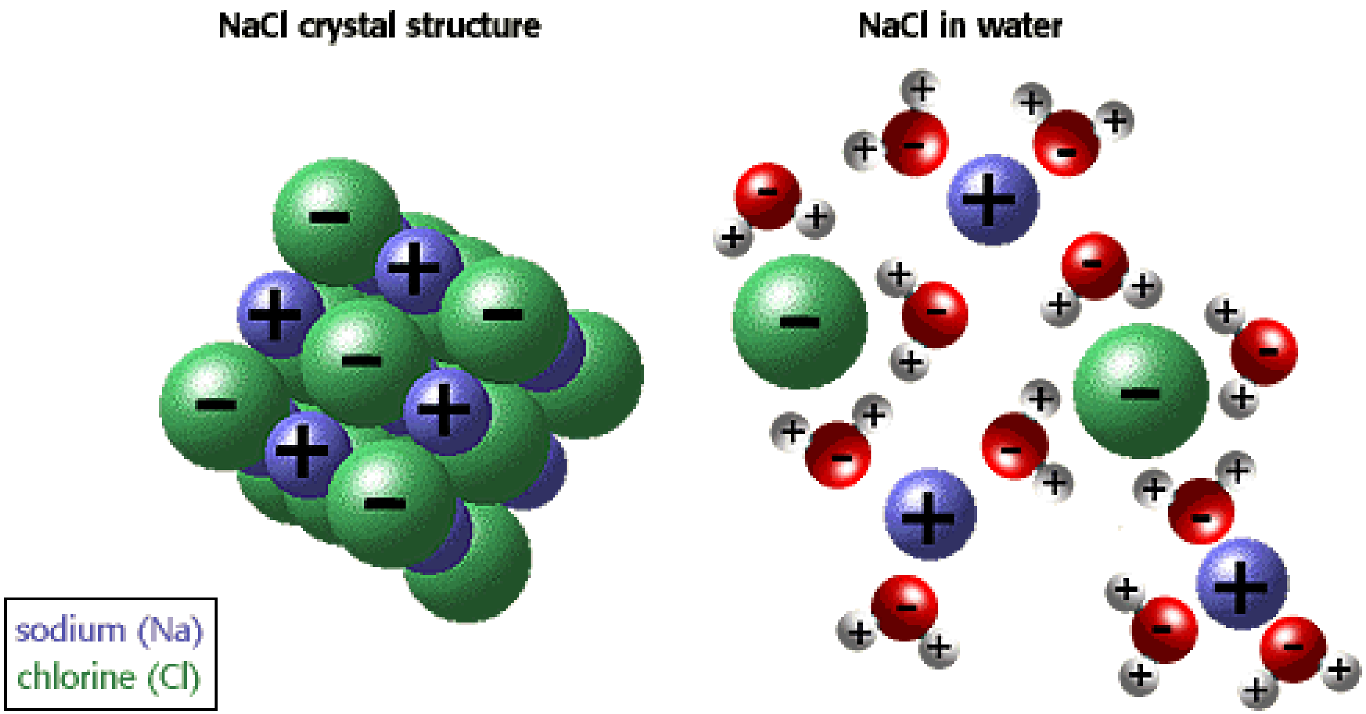
Formation of ions

- Theory of ionization
  - Faraday – electricity made the ions from the solute in the solution.
  - Arrhenius – ions produced by the “ionization” of the particles of the solute.
    - Complete ionization will occur in dilute solutions
    - Dynamic equilibrium will occur in concentrated solutions (ions go back and forth between solution and molecules)

ionic compounds dissolving

- Polarity of water very important
- Dipoles on water molecule attract the ions in the crystal.
- This brings the ions into the solution.
- Energy is released in the process (exothermic)
- Solution processes with water as the solvent is called hydration. This occurs when the ions are surrounded by water molecules.

ionic compounds dissolving



Evaporation of the solvent

- When the water evaporates, the reverse process occurs. The ions will go back together to rebuild the crystals.

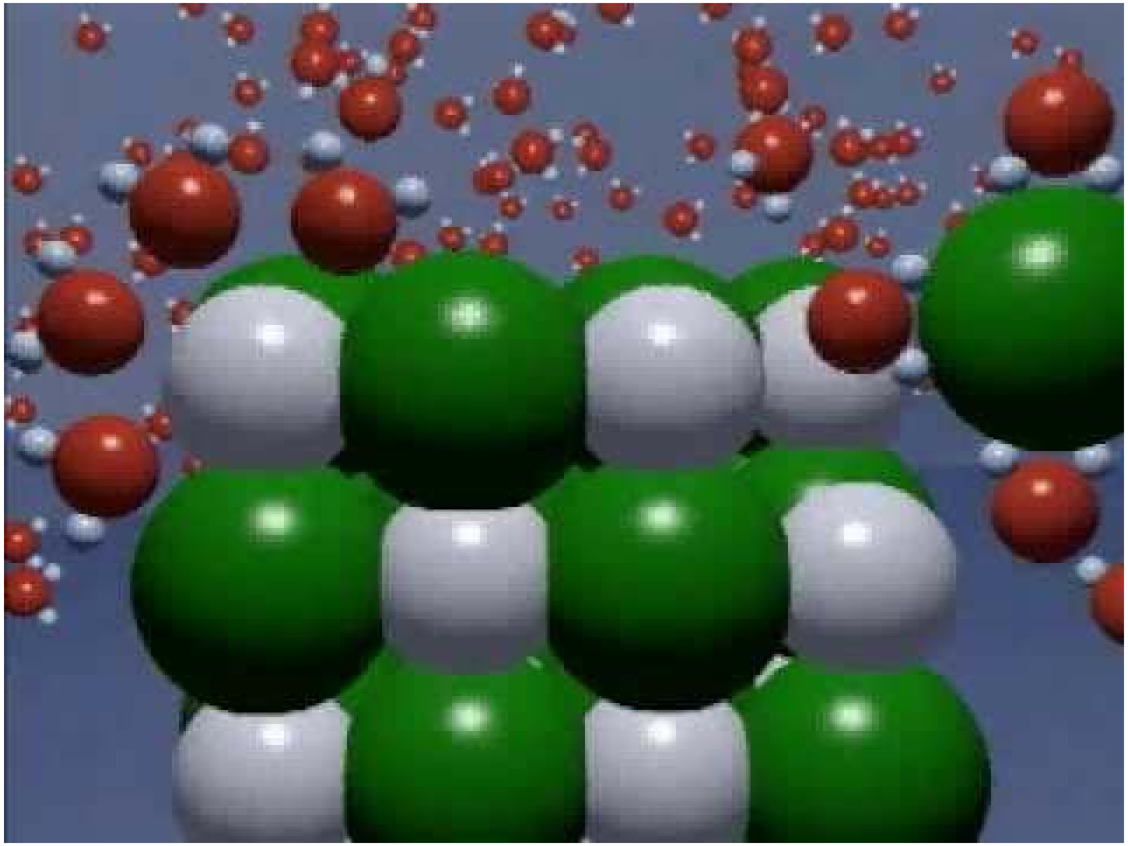
role of energy play in the dissolving process

- The energy released when ions become surrounded by water molecules is called the *heat of hydration.*
- More energy is released when small ions are hydrated then when large ions are hydrated.
- The energy released or absorbed depends on the relative amounts of energy needed
  - 1. To separate the ions in the crystal
  - 2. To hydrate the ions

Dissociation of ionic compounds

- **Dissociation** is a general process in which ionic compounds separate or split into ions.
- The separation of ions that occurs when ionic compounds dissolve in water.

Dissociation of NaCl



Solubility & dissociation related

- How well an ionic compound dissociates in water is how soluble it is
- Ionic compounds have different degrees of solubility from very soluble to very slightly soluble.
- Even those ionic compounds that are "*insoluble*" will dissociate to some degree.

slightly soluble ionic compounds

- in water:
  - An equilibrium will occur between the ions and the crystal
  - The solution will be saturated(has maximum amount of solute at a given temperature)

Solubility of 2 cmpds

- two slightly soluble ionic compounds in water; look like this:
  - $AgCl_{(s)} \rightleftharpoons Ag^{+1}_{(aq)} + Cl^{-1}_{(aq)}$
  - $Fe(OH)_{3\,(s)} \rightleftharpoons Fe^{+3}_{(aq)} + 3\,OH^{-1}_{(aq)}$

precipitation reactions

- When two solutions of highly soluble compounds are mixed together ; they may produce a slightly soluble compound.
- This is really a double replacement reaction.
- The majority of the slightly soluble compound will ***precipitate*** or come out of solution and settle on the bottom of the container.
- The ions of the remaining compound will stay in solution as **spectator ions**.

ionic equations

- Ionic equations show the ions of the compounds in aqueous solutions.
- The ***complete ionic equation*** shows ***ALL*** of the ***ions*** produced by compounds and the slightly soluble compound.
- The net ionic equations shows those ions(on the left) that make up the slightly soluble compound(on the right).

Ionic Equations

- The double replacement version:

$$AgNO_3 + KCl \longrightarrow KNO_3 + AgCl \downarrow$$

- The complete ionic equation:

$$Ag^{+}_{(aq)} + NO_3{}^{-1}_{(aq)} + K^{+}_{(aq)} + Cl^{-1}_{(aq)} \longrightarrow K^{+}_{(aq)} + NO_3{}^{-1}_{(aq)} + AgCl_{(s)}$$

- The net ionic equation will look like this:

$$Ag^{+}_{(aq)} + Cl^{-1}_{(aq)} \longrightarrow AgCl_{(s)}$$

spectator ions

- The ions that do not make up the precipitate and remain in the solution are called *spectator ions*.

Some molecular compounds conduct electricity in water

- So far in our discussion, all of the compounds have been ionic. BUT there are some molecular compounds that will conduct electricity in water solutions.

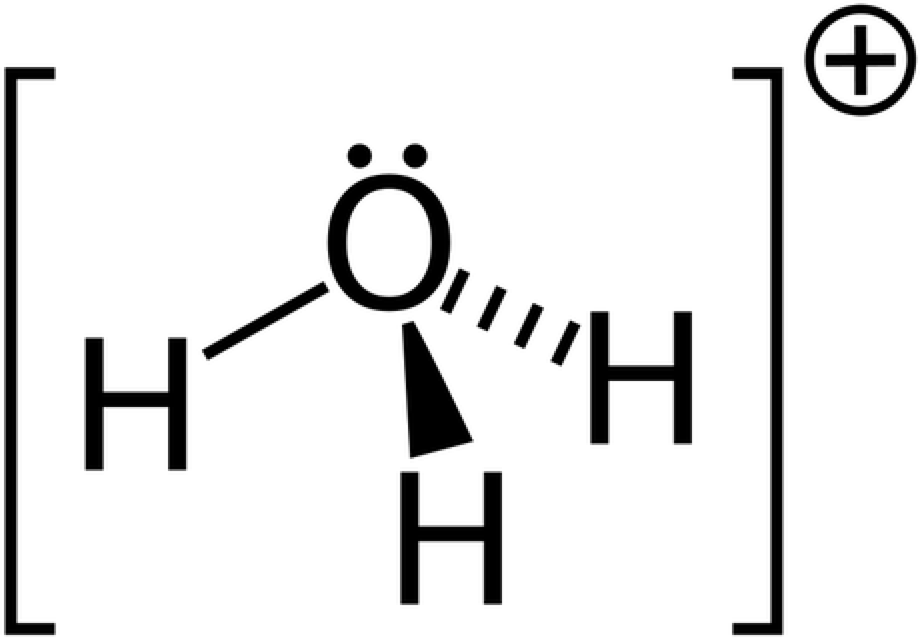
solution process for molecular electrolytes

- When a molecule containing polar bonds is dissolved in water, the dipoles of the water attach to the charged areas of the polar molecules.
- For nonelectrolytes, the complete molecule goes into solution.
- For electrolytes, the weak covalent bonds are broken in the molecule; forming ions.
- Examples of these compounds are: HCl, HF, HBr

Formation of hydronium ions

- When hydrogen ions are formed in a solution a special type of ion forms.
  - Hydrogen ions are just a proton because the electron has been removed or stayed with the more electronegative atom.
  - Hydronium ions are hydrated hydrogen ions.
    - A hydrogen ion with one water molecule.

Hydronium ion



The ion is written this way : H_3O^+

strong and weak electrolytes

- A strong electrolyte is a substance that will completely ionization(come apart 100%) in dilute solution.

Single arrow indicates complete ionization

$$HCl(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

weak electrolyte

- A weak electrolyte is a substance that produces a low number of ions in solution.
  - Example: HF(because HF is in solution as more molecules than ions)

some properties of electrolyte solutions

- Conductivity of solutions
  - These solutions will conduct electricity.
- They will also depress the freezing point and elevate the boiling point of the solvents

fp affected in electrolytes solutions

- Freezing point depression has been observed in solutions produced by electrolytes in water. BUT…….
  - Electrolytes in water appear to amplify this effect.
  - Example:
    - A 1 molal solution of sugar will lower the fp of a water solution to –1.86 ^{o}C.
    - A 1 molal solution will lower the fp of a water solution to approximately –3.72 ^{o}C.

What is apparent degree of ionization?

- If we carefully calculate the fp of a 1 *m* solution of NaCl we find that –3.72 ^{o}C only works at low molal concentrations.
- But at higher concentrations the fp is higher than the predicted –3.72 ^{o}C.
- So does this solute really come apart 100%?

What two things affect the apparent degree of ionization?

- It appears that the number of particles(ions) and their ability to move in a solution has a lot to do with the changes in fb & bp of a solvent(in this case water).
- The attractive forces between the ions and the molecules have a great with this
- A number of water molecules will cluster around an ion. The number of water molecules involved depends on the charge and size of the ion.

So, the apparent degree of ionization depends on…

- The size of these ion-water clusters causes the changes.
- As with any system, an equilibrium will be established. Some ions will go into solution and some will return to the solid crystal.
- The degrees that this occurs is called the Apparent degree of ionization.

Water as an electrolyte

- It appears that water is a very weak electrolyte. This means that water spends most of its time as molecules.
- A few water molecules will ionize to form hydronium ions and hydroxide
  - 2 molecules in 1 billion will ionize

the ionization of water

- The equations to show this looks like this:

$$H_2O \quad + \quad H_2O \rightleftharpoons H_3O^+ \quad + \quad OH^{-1}$$

So absolutely pure water will not conduct much electricity. BUT tap water will and electricity and tap water can be quite dangerous. Why?

remember water is the universal solvent and will dissolve stuff where ever it travels!!!!!

the Debye-Hückel Theory

- The ions of solute are clustered together with ions of opposite charge.
- These clusters can act like individual particles.
- This reduces the total number of particles in the solution thus reducing the predicted effects of the ions on fp & bp.

the Debye-Hückel Theory

- The Debye-Hückel theory is based on three assumptions of how ions act in solution:
- Electrolytes completely dissociate into ions in solution.
- Solutions of Electrolytes are very dilute, on the order of 0.01 M.
- Each ion is surrounded by ions of the opposite charge, on average.

the Debye-Hückel Theory